Characterization of the Superstition Hills fault, Southern California, ruptured in the 1987 M6.6 earthquake, using fault-zone trapped waves

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Non-Technical Summary:

We conducted a seismic experiment in November of 2000 using near-surface explosions at the Superstition Hill fault which ruptured in 1987 *M*6.6 earthquake for study of fault zone structure and physical properties. We deployed 50 PASSCAL REFTEKs in two 500-m-long lines across the southern and northern rupture segments, respectively, as well as in a 1.4-km-long line along the fault trace. The USGS team deployed 178 PASSCAL TEXANs in two lines across the step-over between the northern and southern fault strands. We detonated 2 explosions, using ~500 pounds of chemical emulsions for each shot in 80-feet-deep holes drilled within the southern and northern rupture zones. Explosion-generated *P* and *S*, and fault-zone trapped waves were recorded at portable arrays with a good signal-to-noise ratio. Preliminary examination of explosion-generated data show a low-velocity waveguide existing on the SHF where the shear velocity is reduced by ~30% from the wall-rock velocity. This low-velocity zone is interpreted as the result of dynamic rupture in the 1987 *M*6.6 Superstition Hills earthquake. The waveguides on the northern and southern rupture segments may overlap beneath the fault step-over mapped at surface. A systematic analysis and 3-D finite-difference modeling of the data recorded from explosions, gun-shots and microearthquakes in the experiment will allow us to characterize the more detailed internal structure of the Superstition Hills rupture zone.

Investigations Undertaken:

We have successfully conducted a seismic experiment using near-surface explosions at the Superstition Hills fault, southern California, in November of 2000. We shall use the data recorded in the experiment to characterize the internal structure of the rupture zone of the 1987 *M*6.6 Superstition Hills earthquake.

In the experiment, we deployed two 500-m-long linear seismic arrays, each array consisting of 21 PASSCAL REFTEKs with three-component 2 Hz L22 sensors, across the Superstition Hills fault in the Navy Base near El Centro, southern California (Fig. 1). The two arrays were ~4 km apart from each other, and crossed the 1987 northern and southern rupture segments, respectively. We also deployed a 1.4-km-long array of 8 REFTEKs along the southern rupture segment. The along-fault seismic line intersected the southern cross-fault seismic line to form a cross-shape array.

The USGS seismic team led by Rufus Catchings and Michael Rymer (collaborators of this project) deployed 178 PASSCAL TEXANs with 4.5 and 40 Hz vertical-component geophones along two lines across the fault step-over between the southern and northern rupture segments (Fig. 1). Line 1 was 400 m long and included 108 geophones while line 2 was 170 m long and included 70 geophones.

We detonated 2 explosions SP1 and SP2, using 550 and 350 pounds of chemical emulsions, respectively, in 80-feet-deep cased shot-holes that were drilled within the southern and northern rupture zone (Fig. 1). Shot SP1 was located ~4 km southeast of the southern seismic array while SP2 was located ~1 km northwest of the northern array. Tom Burdette of the USGS shot explosions at 6:30 am and 7:30 am on November 19. The timing of seismic recorders and origin times of explosions were synchronized by the GPS.

After explosions, the southern cross-shape array of 28 REFTEKs remained in the field to record microearthquakes for a couple of months while the northern array was retrieved due to security problem. The USGS team made 80 gun-shots along the TEXAN lines after explosions, and then retrieved all TEXANs from the field.

The explosion-generated data have been transferred from internal hard disks of 50 REFTEKs and 178 TEXANs to tapes and converted to segy-format for analysis. The recording length for each shot was 90 seconds. The sample rate was 500 samples per second. We have examined the three-component data recorded for explosions. The data show a good signal-to-noise ratio for *P* and *S* waves from both SP1 and SP2. Fault-zone trapped waves were also observed although they might be affected by a surficial alluvial layer in the working area. Such a affect has been predicted in our numerical investigation of trapping efficiency of low-velocity fault zone with various geological conditions [*Li and Vidale*, 1996]. We shall carry out a systematic analysis and 3-D finite-difference modeling for the data to delineate the detailed structure near the Superstition Hills fault.

Results:

Figure 2 shows the layout of seismic arrays deployed at the Superstition Hills fault (SHF) zone. The 500-m-long northern seismic array (N. Array) was centered at the northern rupture segment of the SHF which exposed on the ground surface clearly at the array site. The N. Array also crossed the northwest extension of the southern rupture segment although the surface trace of the southern SHF strand is not clear at the northern array site. On the other hand, the 500-m-long southern seismic array (S. Array) was centered at the southern rupture segment which exposed at the site clearly. The S. Array also likely crossed the southeast extension of the northern SHF rupture segment. The cross-fault array included 21 REFTEK recorders, respectively, with uneven station spacings. A 1.4-km-long array of 8 REFTEKs with event station spacing ran along the southern rupture segment. Two tight linear arrays of 178 TEXANs crossed the northern and southern rupture segments at the fault step-over. In the present report, we describe explosion-generated data recorded at REFTEK arrays. The data recorded from microearthquakes and the data recorded at TEXAN arrays will be reported later.

Figure 3 shows three-component data recorded at the along-fault array on the SHF southern rupture segment for explosions SP1 and SP2 which were shot within the southern and northern rupture zones at distance of ~3 km south and ~4 km north of the array, respectively. Because Brawley basement rock is covered by an alluvial layer in the working area, the near-surface explosions produced strong surface waves as shown in the later part of seismograms (Figure 3A). Ground rolls traveled slowly at speed of about 350 m/s so that they were separated from *P*, *S* and fault-zone trapped waves in seismograms (Figure 3B). Fault-zone trapped waves with a long-duration and dispersive wavetrain arrived at the seismic array after *S* waves but before surface waves. Amplitudes of trapped waves are much larger than amplitudes of *P* and *S* waves. We computed the envelope of seismograms using a Hilbert transformation. Amplitude peaks of the envelope denote the arrivals of *P*, *S* and fault-zone trapped waves (Figure 3C), from which we estimated velocities of *P*, *S* and trapped waves: Vp ~ 2.4 km/s, Vs ~ 1.1 km/s and Vfz ~ 0.8 km/s,. The delay of fault-zone trapped waves from *S* waves increased with the distance between the shot and array, showing the existence of a continuous low-velocity waveguide on the SHF southern rupture zone. The shear velocity of the waveguide on the SHF is estimated to be reduced by ~30% from the wall-rock velocity at the shallow depth. We interpret that this low-velocity waveguide on the SHF as being a result of the dynamic rupture in the 1987 *M*6.6 earthquake.

Fault-zone trapped waves were also observed likely at the along-fault array for explosion SP2 even though trapped waves from SP2 passed the fault step-over (Figure 3D). This observation suggests that the step-over mapped at surface between the northern and southern rupture segments is likely a shallow structure. The northern and southern rupture segments may overlap at depth so that trapped waves were not affected by the surficial fault step-over significantly. Alternatively, because the wave length of fault-zone trapped waves at 3 Hz is ~250 m, a narrow step-over between the northern and southern SHF strands would not disrupt trapped waves.

Figure 4A shows three-component seismograms recorded at the northern across-fault array for explosions SP2. *P*, *S* and fault-zone trapped waves generated by SP2 were well recorded. The prominent fault-zone trapped waves with large amplitudes following *S* waves were registered at stations in the southwest part of the array. These stations were located in the step-over between the northern and southern SHF strands. It is noted that amplitudes of trapped waves show maximum peaks at stations close to the northern and southern strands in fault-parallel and fault-perpendicular component seismograms. These observations further suggest that the low-velocity waveguides on the northern and southern rupture segments may overlap at depth beneath the step-over.

Figure 4B shows three-component seismograms recorded at the northern array for the southern explosion SP1. Fault-zone trapped waves arrived at stations close to the southern and also northern fault strands between 10s and 15s in the fault-parallel and fault-perpendicular component seismograms. We estimated Vp ~ 2.5 km/s, Vs ~ 1.1 km/s, and Vfz ~ 0.7 km/s at 3 Hz, consistent with those in Figure 3. We also noted that trapped waves were not disrupted by the step-over in this case, suggesting again that the low-velocity waveguides on the southern and northern rupture segments may overlap at depth.

We shall analyze all data recorded from explosions, gun-shots and microearthquakes in the experiment and do 3D finite-difference modeling of fault-zone trapped waves for a more detailed delineation of the Superstition Hills rupture zone and fault step-over.

Data Sets:

The explosion data recorded by 50 PASSCAL REFTEKs and 178 TEXANs have been copied on tapes in segy-format. The REFTEK data are processed by YongGang Li of USC (the P.I. of this project). The TEXAN data are processed by Rufus Catchings and Michael Rymer of USGS (collaborators of this project). The data are available through
YongGang Li (Tel: 213-740-3556, E-mail: ygli@terra.usc.edu) and Rufus Catchings (Tel: 650-329-4749, E-mail: catching@sanandreas.wr.usgs.gov).

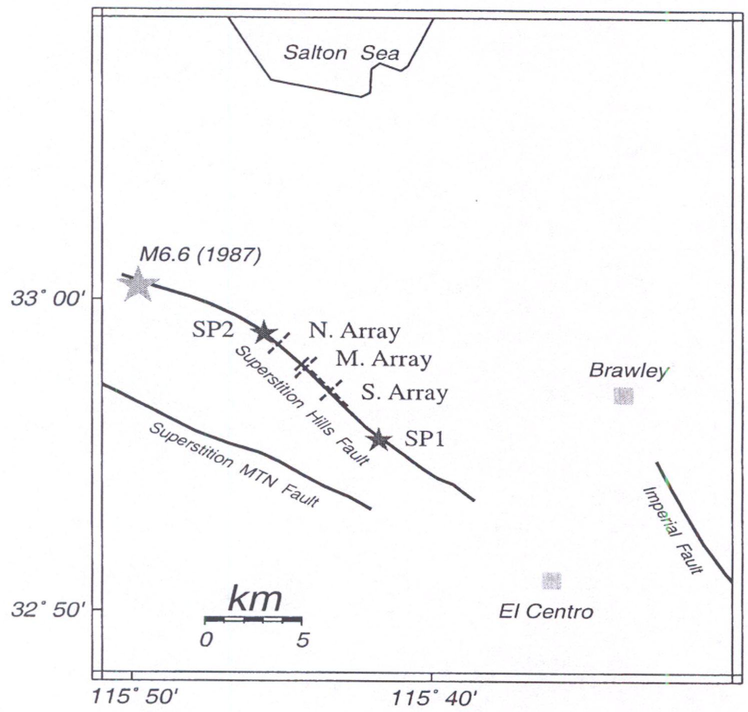

Figure 1. Map shows locations of portable seismic arrays and explosions at the Superstition Hills fault, southern California, in November, 2000. The fault ruptured in the M6.6 earthquake occurring on 24 November, 1987. The total length of surface breaks along the SHF was ~20 km. The southern and northern rupture segments overlapped at the fault step-over in the middle portion of the SHF.

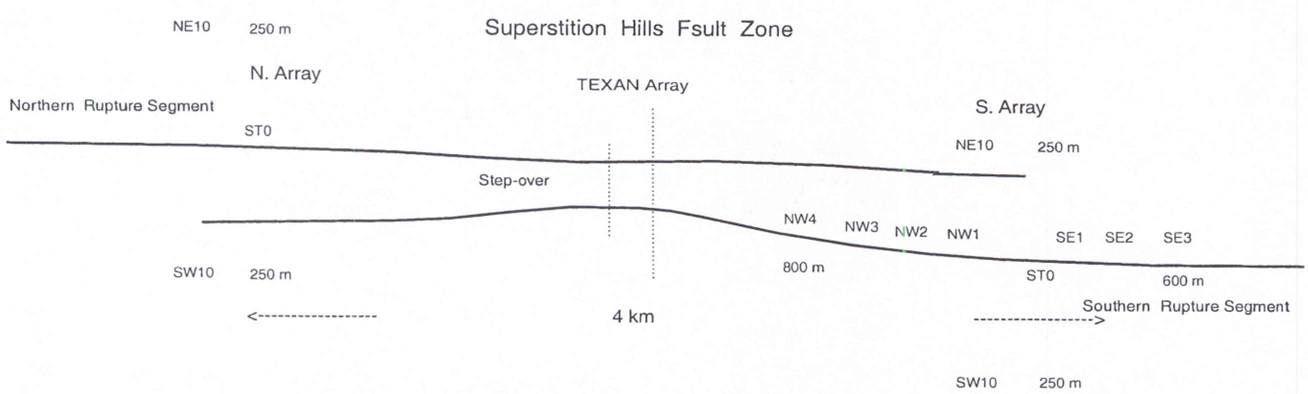

Figure 2. Layout of seismic arrays deployed at the Superstition Hills fault. A fault step-over is between the northern and southern rupture segments of the 1987 earthquake. The northern and southern cross-fault arrays consisted of 21 three-component REFTEK stations for each, with 12.5 m station spacing for 9 stations in the middle of the array, 25 m for 8 farther stations and 50 m for 4 end stations. 8 REFTEK stations were deployed along the southern rupture segment with the even station spacing of 200 m. The USGS arrays of 178 TEXANs were deployed on lines across the central portion of fault step-over. One line is 400 m long and another line is 170 m long, with station spacings of 2.5 and 5 m.

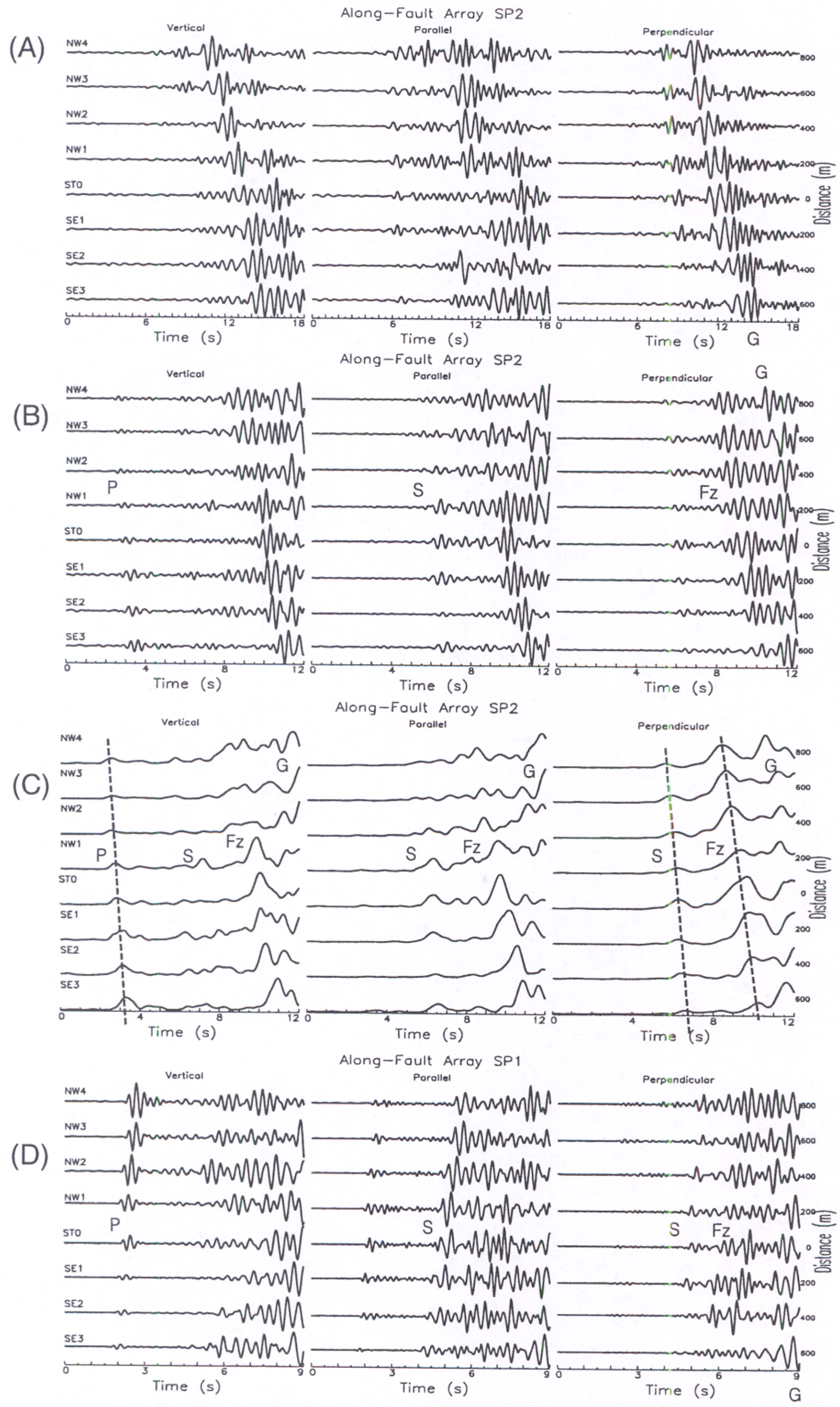

Figure 3. Vertical, fault-parallel and fault-perpendicular components of seismograms recorded at 8 REFTEK stations along the southern Superstition Hills rupture segment for explosions SP1 and SP2. (A) shows strong surface waves in the late part of seismograms generated by shot SP2. (B) shows P, S and fault-zone trapped waves in the early part of seismograms generated by shot SP2. The long-duration wave trains of fault-zone trapped waves follow S waves. (C) shows envelopes of seismograms in B. The peaks marked by dashed lines denotes arrivals of P, S and trapped waves. (D) shows P, S and fault-zone trapped waves in seismograms generated by the northern shot SP1.